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No. 406

FLAP GEAR FOR AIRPLANES

A New Scheme in Which Variation is Automatic

By A. Hessell Tiltman

From "The Automobile Engineer," February, 1927

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS.

TECHNICAL MEMORANDUM NO. 408.

FLAP GEAR FOR AIRPLANES.\*

A New Scheme in which Variation is Automatic.

By A. Hessell Tiltman

Introduction

The idea of combining the advantages of the high-efficiency airfoil with those of the high-lift wing section by means of an arrangement which hinges the trailing portion is by no means new. At an early stage in the history of aeronautics, this principle was embodied in various designs in an attempt to reduce the landing speed, and since then many types having such a system have been put into production. These notes deal more particularly with one design of such a gear, which functions automatically and therefore requires no attention on the part of the pilot. The writer believes that Monsieur Breguet, the well-known French designer, was one of the first to employ the automatically controlled type of gear. The present installation, however, has several original features which may be of some interest.

The basic idea of any system of flap gear is to give the airplane an increase in speed range and, since an addition of the order of 10 per cent is usually obtained, generally speaking

\*From "The Automobile Engineer," February, 1927.



it may be said to justify its existence.

This introduction would scarcely be complete without some reference to the investigations which are at present being carried out by Mr. Handley Page and others on slotted wings. The slots, which are variable and are of special design, extend along the span of the airplane, the width of the aperture being controlled by the pilot. Increase in speed range is one of the claims for the system. It is, however, outside the scope of this report to deal more fully with the design and functioning of this gear.

In Fig. 1 is shown the effect on the aerodynamic characteristics of an airfoil (in this case section R.A.F. 9) of varying the angle of the trailing portion to the main chord. It will be noticed that the lift/"drag" ratio for low values of  $C_L$ , corresponding to full and cruising speeds, is considerably higher for a flap setting of 5 degrees up, whereas the value of maximum  $C_L$ , which corresponds to landing speed, is steadily increasing even at a flap angle of 20 degrees down. The maximum flap angle which it has been found convenient to use in flight, is between 12 degrees and 15 degrees down. Therefore, to illustrate the benefit derived, an envelope, shown on the graph by means of a dotted line, has been drawn to embrace the maximum ordinates of the curves between flap angles 5 degrees up and 12 degrees down. This envelope represents approximately the characteristics of such an arrangement, provided the flap



is at its optimum position for a given angle of incidence.

One of the most difficult problems confronting the modern designer is that of reducing to an absolute minimum the multitude of controls, instruments, etc., which require constant attention on the part of the pilot. The addition of a single lever which could possibly be dispensed with is looked upon by "commercial" designers with misgiving. A variable flap gear, which would function automatically and require no attention during flight appeared, therefore, an attractive idea even in the early stages of its development.

The advantages of variable camber may be classified as follows:

(a) Definite increase in speed range at the cost of the extra weight involved by the addition of the various units comprising the complete gear. This extra speed range is more usually, though not necessarily, associated with reduced landing speed. Some idea of the benefit derived may be obtained by estimating the area which would require to be added to the main wings to give a reduction of, say, 7 M.P.H. in stalling speed. For an airplane of normal performance it would be about 30 per cent, and it must be realized that to make the comparison a fair one the areas of the various surfaces of the empennage, the length of fuselage, etc., must also be increased in their correct proportions. The extra weight involved by the increase in size of the airplane must be considerably more than that



caused by the addition of flap gear.

(b) Greater ground angle, i.e., the angle between the chord of the main wings and the ground. This is always an advantage, as it decreases the run of the airplane on the field when landing. Alternatively, if the ground angle be considered sufficient, the landing gear can be reduced in height if propeller clearance permit.

(c) When approaching the field preparatory to landing, the airplane having its flaps in the down position, takes up an attitude in the air about 10 degrees more nose down than would be the case with a normal airplane. This gives the pilot a better view at the moment when he most urgently needs it. Unfortunately, the question of view is one which is seldom given sufficient weight when a new airplane is being laid out.

The main utility of any type of flap gear may be said to be the assistance it affords the pilot, who in the sudden emergency of engine failure near the ground has to make a rapid survey of possible landing spaces, maneuver the airplane so as to lose height to the best advantage, and finally to effect a landing according to his hastily devised plan. It is precisely at such a moment that the pilot has no time to devote to the manipulation of any but the absolutely necessary controls. On such an occasion when it is most needed he would probably fail to bring the flap-operating mechanism into play. However, with a system of flaps automatically controlled in their operation by the speed



of the airplane, the pilot need hardly know of its existence, yet whenever he makes a landing he is certain of obtaining the full advantages of such a mechanism.

It is realized that it may not be possible to so design an automatic gear that the flaps are always in their optimum position, and it has been suggested that it is in this respect that a hand-operated type would score. This argument is probably more apparent than real, as it presupposes technical knowledge and conscientiousness on the part of the pilot which in some cases he does not possess. In practice it is more likely that the gear lever will remain unmoved for considerable periods.

Since the very early days Capt. Geoffrey de Havilland has shown considerable interest in the possibilities of variable flaps. In conjunction with his Chief Assistant, Mr. A. E. Hagg, he conceived the idea of producing a gear which would function automatically, be foolproof in operation, and require no attention on the part of the pilot. The design of such a gear obviously presented many difficulties, but after much patient investigation a design has been evolved which can be said to have passed the purely experimental stage and appears now to have justified the money spent on its development.

#### Functions and Advantages

Before dealing with details of the later designs, it might be well to reiterate the claims put forward by those responsible



for its evolution.

(a) No control or technical knowledge required by pilot to fly airplane so equipped with maximum efficiency.

(b) The gear ratio between the control stick and the ailerons can be made to vary automatically with the speed of the airplane. This is a very desirable feature.

(c) The ailerons can still be given any required amount of differential movement, and it has been found possible to make this control so effective near stalling speed that an airplane so fitted should be safer to fly.

(d) The minimum landing speed and distance to pull up on the ground are always available in an emergency.

(e) In addition, all the claims put forward in support of the hand-operated type of mechanism apply equally to this gear.

### Design

The following airplanes have been fitted with automatic variable flaps since 1923: D.H.9, D.H.6, D.H.50, D.H.51A, D.H.54 (designed especially to have this type of gear), and "Bristol Fighter" (converted purely for experimental work for the Royal Aircraft Establishment at Farnborough). It must be admitted that on the first three airplanes so equipped the gear was crude and not altogether satisfactory, and may therefore have given a poor impression to those who flew them. The last three airplanes, however, have more than justified the faith



which the designers placed in the principle.

It is not considered necessary to cover all the various phases in the development of the gear, but the very early attempts are of some interest in showing the ideas upon which the design was founded in the first instance. At the beginning it was hoped to gain the desired results by simply fitting a spring unit in series between the aileron operating control and the flaps. In practice this gave only indifferent results, and the aileron control was found to have become relatively ineffective. An explanation was soon found, and it was discovered that when, for example, the port aileron was depressed, a greater load was imposed upon it, and in consequence it traveled part of the way up against the spring control. The starboard aileron, now being in the up position, was partially relieved of its load and traveled downwards to a position of equilibrium. To overcome this difficulty, the port and starboard ailerons were interconnected by a system of cross cables. This ensured that as regards purely flap travel both mechanisms take up the same position. The aileron control was merely superimposed upon this flap movement.

Figs. 2 and 3 show a purely diagrammatic sketch of the gear in its finally developed form. For the sake of clearness the two mechanisms B and C which, although interconnected, are separate and distinct units, have been shown mounted on separate spindles. The lengths of the various levers and their angular



travels are not necessarily relatively to scale, but the amount of differential effect on the various levers is, however, approximately correct. By differential effect is meant the placing of the lever at an angle other than 90 degrees to its connecting rod in its mid-position. The result of such an arrangement is that equal angular movements of one lever give a progressively increasing or decreasing angular movement to the lever at the other end of the connecting rod. The very widely employed differential aileron mechanism is a typical example of this principle. It has proved so valuable in improving control that the same idea in a modified form has now been embodied in the rudder and elevator control to great advantage. In the case under review, differential effect has been utilized in the design to serve three purposes:

- (a) To give differential movement to the ailerons.
- (b) To provide a variable gear ratio to aileron control with variation in flap angle.
- (c) To obtain the correct movement of the flaps at the speeds required.

The diagrams show an inner set of flaps which simply moves up with increase of speed, and an outer set which has superimposed on its flap movement a movement, controlled by the control stick, giving the usual aileron control. The D.H. 54, a large 14-passenger airplane weighing 11,000 pounds, fully loaded, and having a Rolls-Royce "Condor" engine, was installed with this



system in order to make the aileron control as light as possible and to reduce structure weight. The other airplanes had the inner system of flaps, marked A in the diagrams, omitted, the outer system B and C being made to cover the full span.

### Spring-Control Mechanism

Very early in the experimental stage it was found that the spring control gear must be such that as the flaps moved up with increase of speed, it would be necessary to arrange that the resistance moment imposed upon the main spindle by the spring must at least not appreciably increase, but preferably become smaller. In the early attempts a long length of rubber shock absorber, extending the span of the extension plane, was employed. In the later designs, however, a decreasing moment was obtained by the arrangement shown diagrammatically in Fig. 4, where arbitrary figures for spring load and lever arm have been used to illustrate the principle. It will be noticed that by rotating the spindle, in spite of the spring tension increasing from 200 to 300 pounds, the torque has been decreased from 1000 lb.-in. to 600 lb.-in. In this way a short stiff spring of quite reasonable weight can be employed.

### Final Stages in Design

The final stage in the design was to superimpose the two mechanisms B and C upon the same spindle. This step was found



to have the following advantages:

(a) Compactness and lightness of mechanism.

(b) The gear could be built up as one complete unit, tested for its adjustment, and dropped into its position in the airplane.

(c) Greater rigidity.

(d) Ease of adjustment during trials.

(e) Smaller and fewer inspection doors in airplanes.

In determining the final lengths of the various levers and their respective differential settings, the designer had to be very careful to guard against certain dangers. The indiscriminate use of differential effect might lead him into two troubles. Firstly, too much differential in the aileron control system, without a compensatingly high gear ratio, might cause the ailerons to become overbalanced and take charge in the air at low speeds. Secondly, too much differential effect on the flap-operating levers, might cause the resultant to pass too near the dead center position and, even if the gear did not become locked, it had the effect of causing the flaps to move up too rapidly. However, although the analysis of the moments on the various spindles is somewhat complex, the principles governing the movement of the levers are now thoroughly understood, and there need be no trouble from either of these causes. In passing, one point should be emphasized, and it is common to all methods of differential aileron control, irrespective of



the inclusion of flap-operating mechanism in the system. It is that there seems to be no doubt that a large amount of differential movement is wholly beneficial as long as the aileron travel is sufficiently large. The combination can be made to give both a light and very efficient control, particularly near stalling speed. It also gives a yawing moment to the airplane in the correct direction, thus reducing the rudder movement necessary to put the airplane into a correct bank. It should be realized that aileron differential and gear ratio go hand in hand.

The ideal position that the flaps should take up at various speeds is largely a matter of compromise, as the considerations of unsticking and landing are somewhat antagonistic. The following, however, is considered to be somewhere near the optimum arrangement:

Stalling speed - flaps right down, say 12 degrees.

5 M.P.H. above stalling speed - flaps start to move up.

10 M.P.H. below cruising speed - indicator registering zero angle.

Cruising speed - flaps right up, say 2 degrees above zero position.

Fig. 5 gives a curve derived from figures taken during flight on a D.H. 54, and it will be seen that the result is not far from ideal. When the airplane is only lightly loaded, the position of the curve is not substantially altered, the landing, cruising, and full speed points, however, spread out a small amount.



Care is required in designing the cable system to ensure that it is harmonic in all its movements, i.e., that there should be no loosening or tightening of the cables in any position. If this effect be present even in a small degree, it would quickly become noticeable since it is necessary to make the whole system very rigid. By studying Figs. 11 and 13, it will be seen that pains have been taken not only to obtain this rigidity, but also to eliminate any backlash, by the employment throughout of ball bearings on all rotating parts. The importance of this can quickly be seen when it is realized that it is usually necessary to house the operating units within the wings, where the depth available for the cables to clear the rib flanges is extremely limited.

#### "Bristol Fighter"

Figs. 6, 7, 8, and 9 give some idea of the single unit type of installation as fitted to a standard "Bristol Fighter." This system is similar to that shown diagrammatically in Figs. 2 and 3, except that unit "A" has been omitted. It follows very closely the arrangement employed on the D.H. 54, the gear being housed within the lower wing, and the top and bottom flaps being joined by connecting rods.

#### D.H. 54

Figs. 10, 11, 12, and 13 show the inner and outer units corresponding to A, B, and C, respectively, in Figs. 2 and 3. It



will be seen that the flap-operating levers travel between two curved bridges, which are fitted with adjustable stops, by means of which the flap travel can be set on the ground to work between any desired limits, or can be locked in any required position. This makes for safety when the airplane is undergoing its first trials, and is flown lightly loaded with the flaps locked in the neutral position. The aileron control is, of course, not affected by this, except that it is not so effective at low speeds.

The four units complete weigh 44 lb. It has been estimated that the total additional weight incurred by the installation of variable flaps, is of the order of 200 lb. Most of this weight is accounted for by the flap spars which would, of course, be characteristic of any type of flap gear, and it is doubtful whether the figure of 44 lb. is greater than that represented by a hand-controlled gear on an airplane of the same size.

#### Construction of Units

Most of the levers in the D.H. 54 were built up of 3-14 gauge mild steel plates, having 3/16 inch thick aluminum riveted between, tapering towards the tip, the aluminum being replaced at the ends by mild steel packing pieces soldered in position. Also on this airplane mild steel was used for all ball-race housings, etc. On the "Bristol Fighter," however, the levers were solid 4 gauge duralumin with ball-race housings machined from duralumin bar.



### Change of Trim of Airplane

From wind-tunnel curves showing variation of center of pressure with change in flap angle it had been anticipated that one would have to be prepared for considerable variation in the trim of the airplane with change of speed, and rather more than is encountered on standard types. Fortunately, this has not been found to be the case, and it is possible to fly the D.H. 54 at all speeds with very little adjustment to the tail trim wheel.

### Reliability

The possibility of breaking or stretching the springs has been put forward as an argument against the reliability of the system. Absolutely no trouble has been experienced from this cause during a very extensive series of trials, and it should be pointed out that in the case of the "Bristol Fighter" design the springs are virtually duplicated and of the D. H. 54 quadruplicated, as they are interconnected by the balance cables. In the event of trouble from this cause, the flaps would simply travel upwards until they attained equilibrium, their range of flap positions merely operating at lower speeds.

Wherever it has been considered expedient to duplicate cables, shackles, and pins, levers have been made particularly robust to guard against fracture.



### Production and Maintenance Costs

Up to the present time no airplanes having this type of gear installed have gone into production, as all the airplanes so equipped have been considered experimental. In consequence, wherever possible, adjustments have been provided so that the best results could be obtained based on full-scale trials. There should be no difficulty, however, in designing an airplane having all its leverages and travels fixed. This should considerably reduce the cost of manufacture, while the question of rigging should present no more difficulty than an airplane fitted with the standard type of controls.

### General Conclusions

The writer has been so closely associated with the design and testing of the gear described in this report, that it may be difficult for him to form an unbiased opinion on its practical utility. The following analysis, however, is a genuine attempt to consider its various features from the point of view, for example, of the chief engineer of an air line, who would be responsible for its maintenance and who would be specially concerned with such fundamentals as initial and maintenance costs, balanced against improvement in speed range, lower gasoline consumption, or greater load-carrying capacity as the case may be.



(a) The extra initial cost of the gear has, of course, been somewhat high in its experimental stages. This was inevitable, and is generally associated with any departure from standard practice. However, those responsible for the origination of the idea, consider that on even a semi-production basis, the extra cost of manufacture could be reduced to a point where it was definitely worth while.

(b) Maintenance could doubtless be reduced by simplification in design to little more than the care required on airplanes fitted with standard controls. Pulleys have been eliminated where possible, and extra stout cables have been employed, otherwise the cables do not touch any portion of the airplane and should, therefore, last indefinitely. Since all ball-races are greased before assembly, and are fitted with dust caps, lubrication should only be necessary at long intervals. If considered desirable, any of the well-known greasers could easily be fitted, and the gear be charged with the grease-gun.

(c) The following are various points of interest affecting the performance of airplanes fitted with this system:

1. Unstick.— One cannot do better than quote the opinion of the technical staff of the Martlesham Heath Experimental Station, where an extensive series of trials was carried out on the D.H. 54. This airplane was tested over the screen fully loaded, both with flaps operating and with flaps locked in the up position. In their opinion the flap gear justified its ex-



istence in this respect, which is the one in which there might be some doubt because, although the rate of climb was not appreciably increased by the use of flaps, the climbing speed was reduced by about 5 M.P.H., and on an average day with a wind of say, 8 M.P.H., this would increase the angle of climb from about 1 in 10 to 1 in 9.

2. Rate of Climb.— Some small increase in favor of using the flaps.

3. Cruising and Full Speeds.— In both these cases, the flaps being in the up position, the speeds are, of course, normal. However, if the gear be adjusted to give the flaps an upward trail of say, 2 to 3 degrees, these speeds should be improved by about 2 M.P.H.

4. Stalling Speed.— Reduced by 7 to 8 M.P.H. This figure represents an average taken from a large number of observations during full-scale trials carried out on the various airplanes fitted with the gear.

5. Speed Approaching Airport.— This is reduced by about 5 M.P.H., also the airplane takes up an attitude with its nose well down, and the view forward is correspondingly improved.

6. Pull up on Ground.— In the opinion of several well-known pilots who have flown the D:H. 54 during its trials,



this airplane should be particularly easy to handle in a forced landing. Any improvement in this characteristic is most important, and is certainly a step in the right direction.



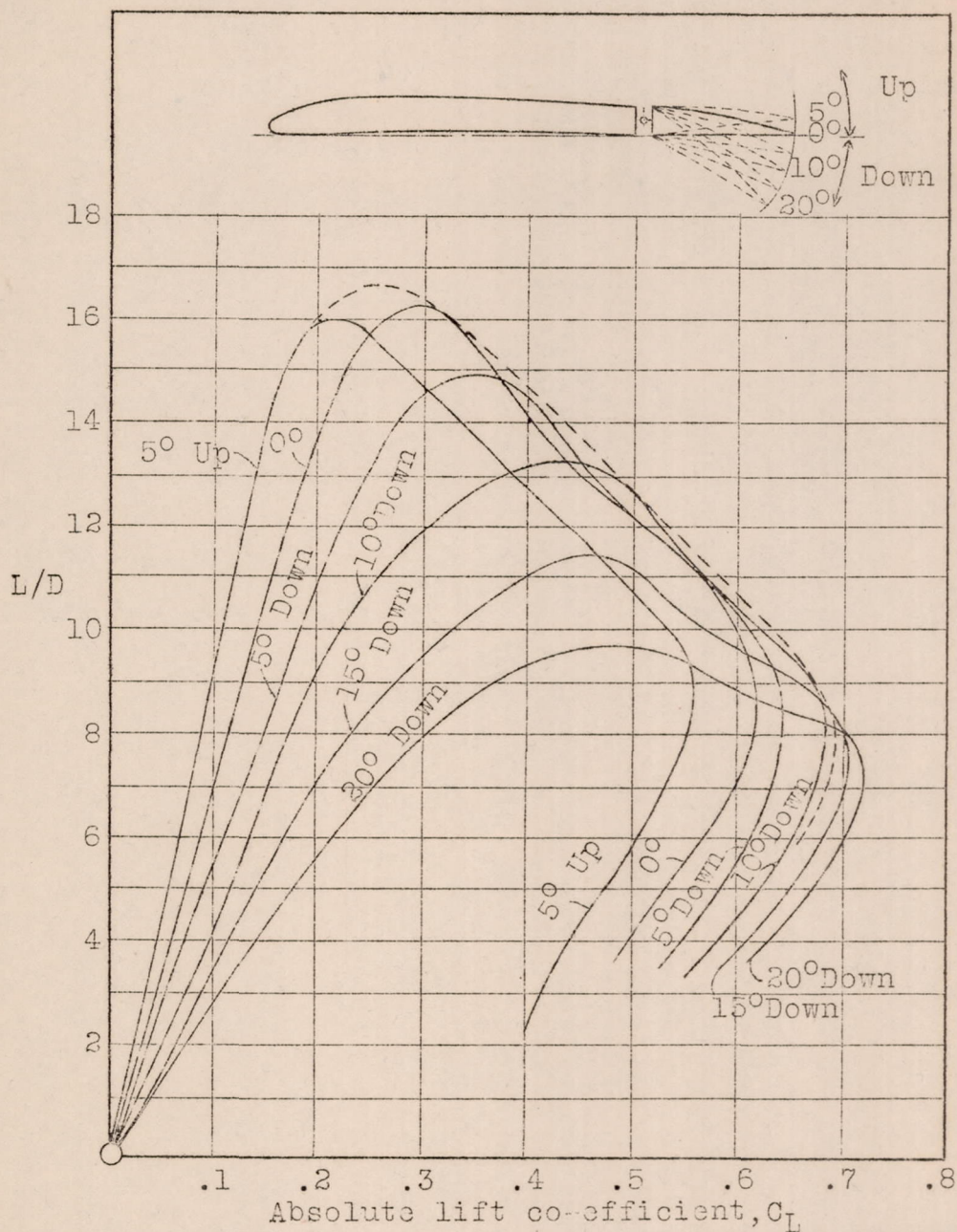


Fig.1 Curves showing effect of flap angle on  $L/D$  plotted against  $C_L$ . Wing section R.A.F.9.



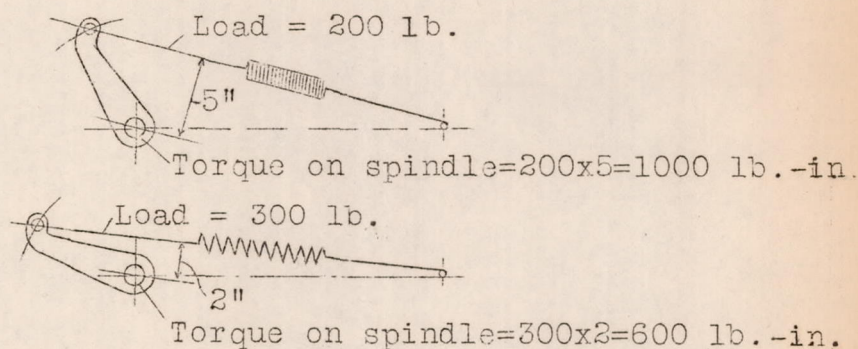


Fig.4 Diagram showing reduction of torque on spindle with increase of load in spring.

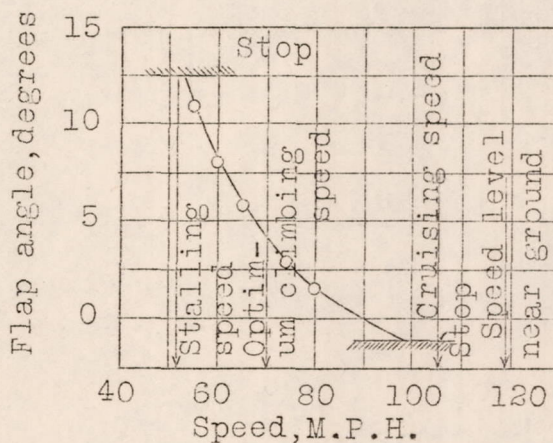


Fig.5 Relationship between flap angle and speed for D.H.54 fully loaded.



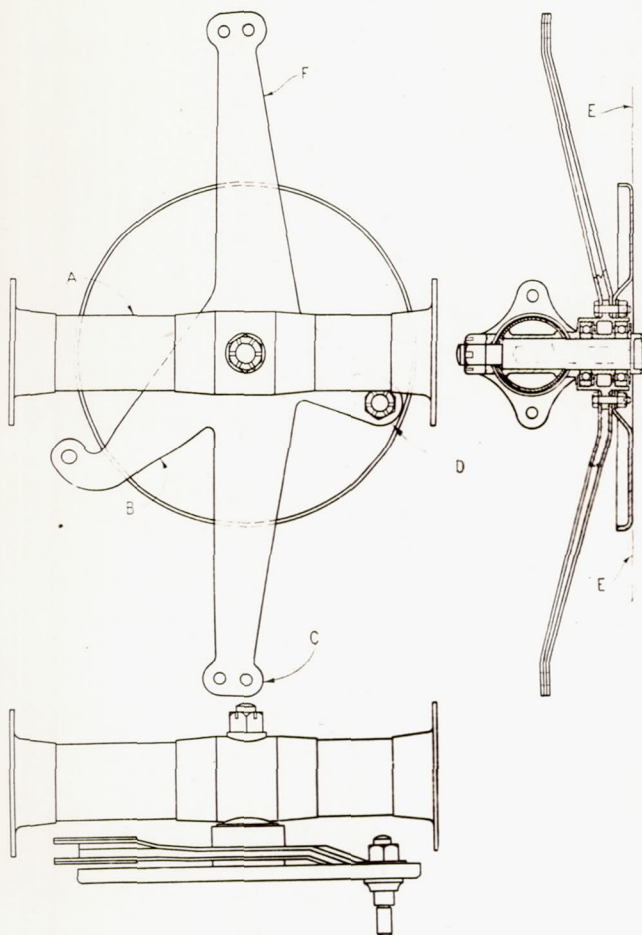


Fig. 11.

Arrangement of inner flap operating mechanism on D.H.54.

- A Main bracket.
- B Lever connected to spring control.
- C Lever connected to flap balance cables.
- D Lever connected to lever connecting rod.
- E Lower surface of plane.

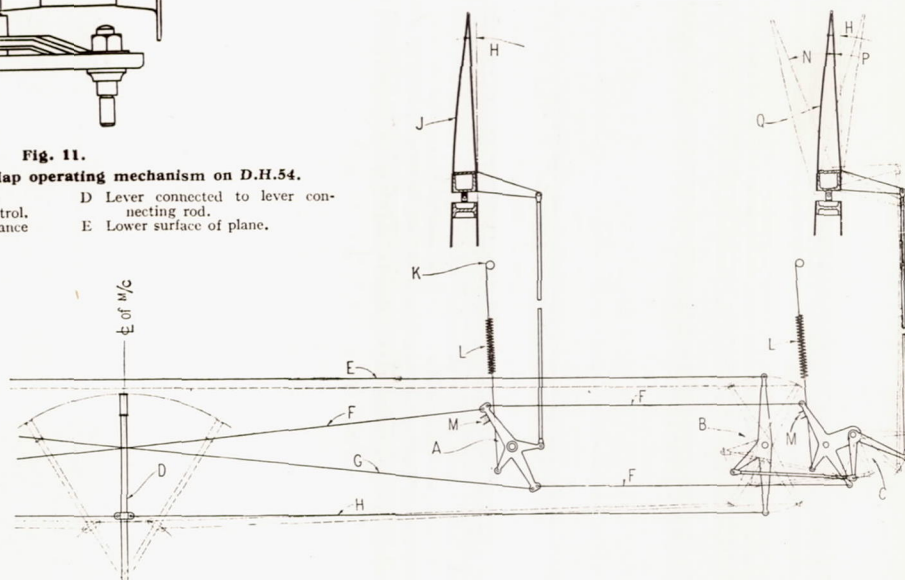


Fig. 2.

Flaps in up position, and ailerons up and down.

- A Flap operating gear.
- B Aileron operating gear.
- C Flap operating gear.
- D Joy stick.
- E Aileron balance cable.
- F Flap balance cable.
- G Aileron control cable.
- H Flap travel.
- J Inner flap.
- K Spring tension adjustment spindle.
- L Spring.
- M Flap travel stop.
- N Aileron travel up.
- P Aileron travel down.
- Q Outer combined flap and aileron.

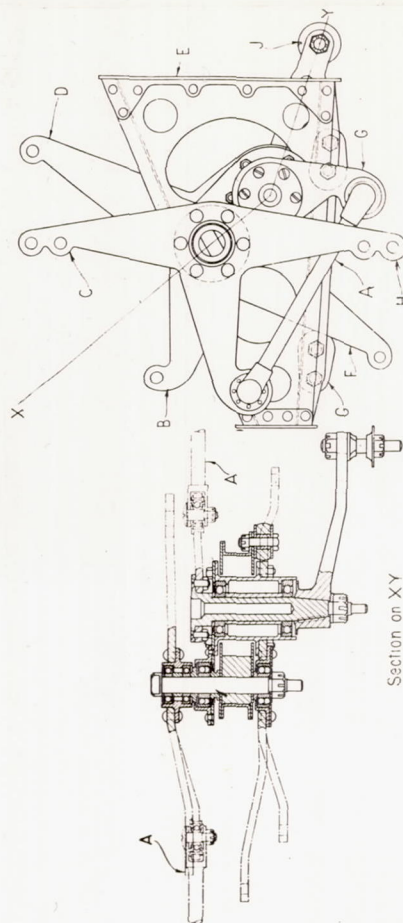


Fig. 7.

General arrangement of single unit flap and aileron operating gear on "Bristol Fighter."

- A Top connecting rod.
- B Lever connected to spring control.
- C Lever connected to balance cable.
- D Lever connected to flap balance cable.
- E Main bracket.
- F Lever connected to flap balance cable.
- G Stop.
- H Lever connected to aileron control cable.
- J Lever connected to lower connecting rod.

Section on XY



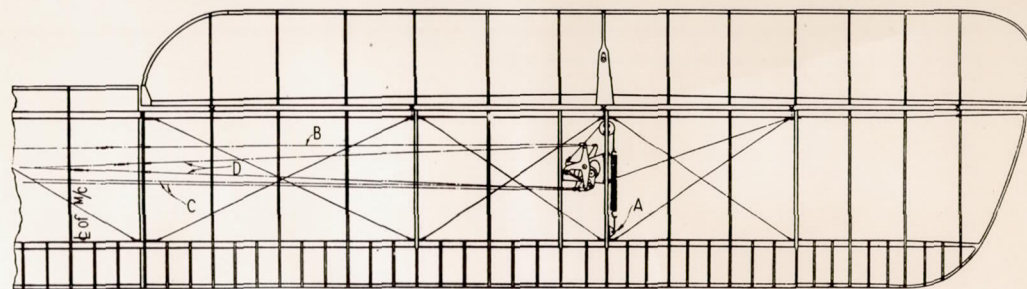


Fig. 6.

Arrangement of single unit flap gear installed in "Bristol Fighter."

A Spring tension adjustment gear.  
B Aileron balance cable.

C Aileron control cables.  
D Flap balance cables.

E Inter-flap connecting rod.  
F Lower connecting rod.

G Lever giving adjustment to both leverage and differential effect.

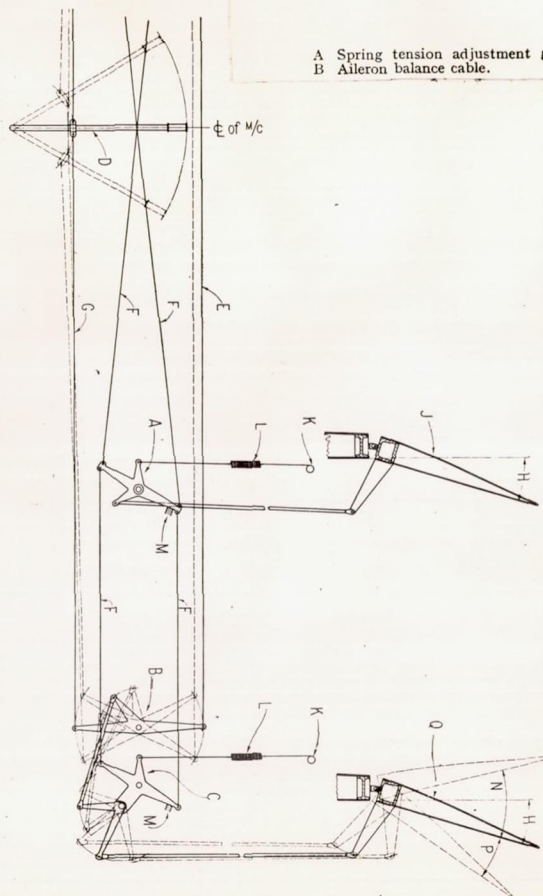


Fig. 3.

Flaps in down position and ailerons up and down.

For reference letters see Fig. 2.

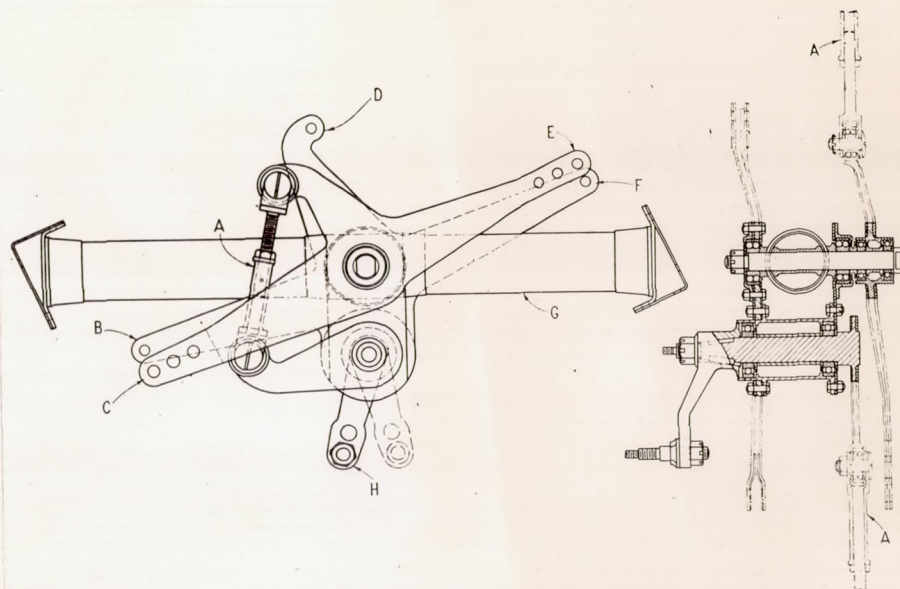


Fig. 13.

Arrangement of outer combined flap and aileron operating mechanism on D.H. 54.

A Top connecting rod.  
B Lever connected to flap balance cable.  
C Lever connected to aileron control cable.

D Lever connected to spring control.  
E Lever connected to aileron balance cable.  
F Lever connected to flap balance cable.

G Main bracket.  
H Lever connected to lower connecting rod.



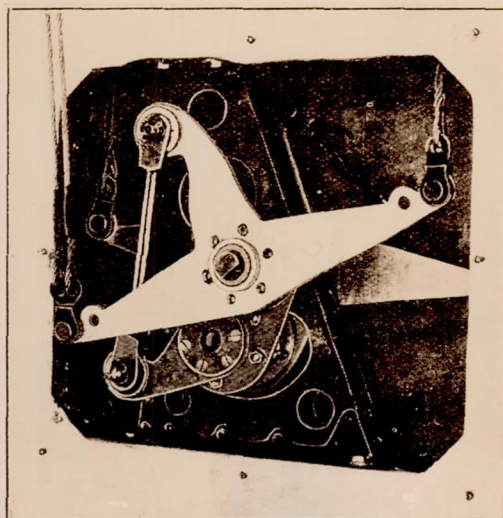


Fig. 8.  
Flap and aileron operating mechanism on  
"Bristol Fighter."

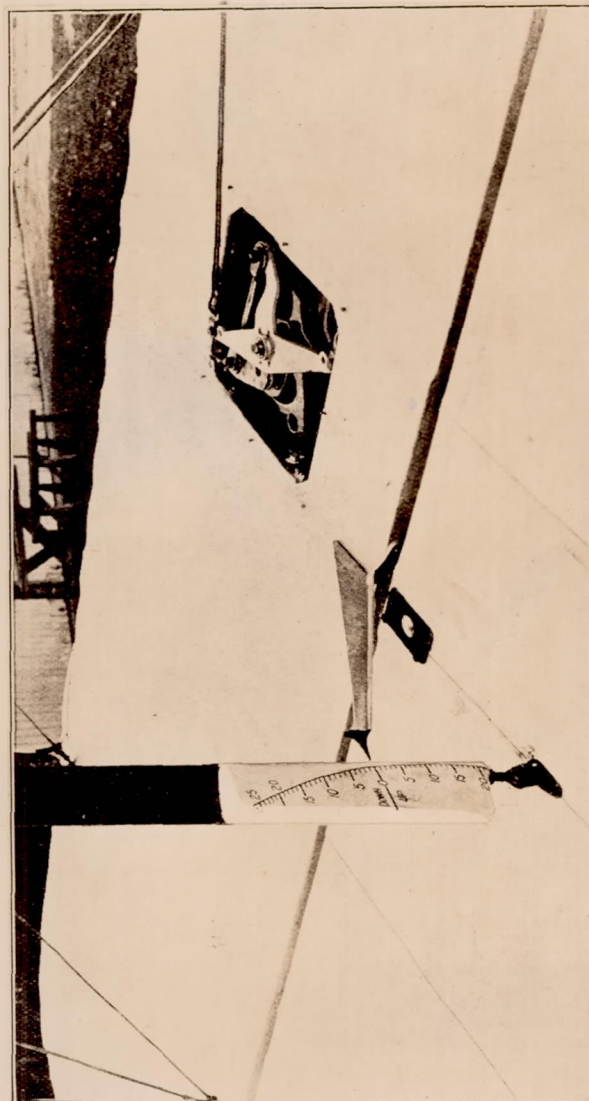


Fig. 9.  
Flap and aileron operating mechanism, showing flap angle indicator on "Bristol Fighter."

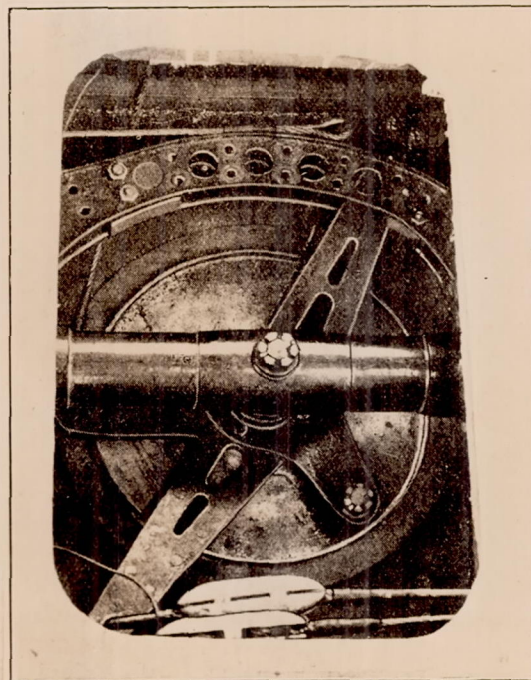


Fig. 10.  
Inner flap operating mechanism on D.H.54.

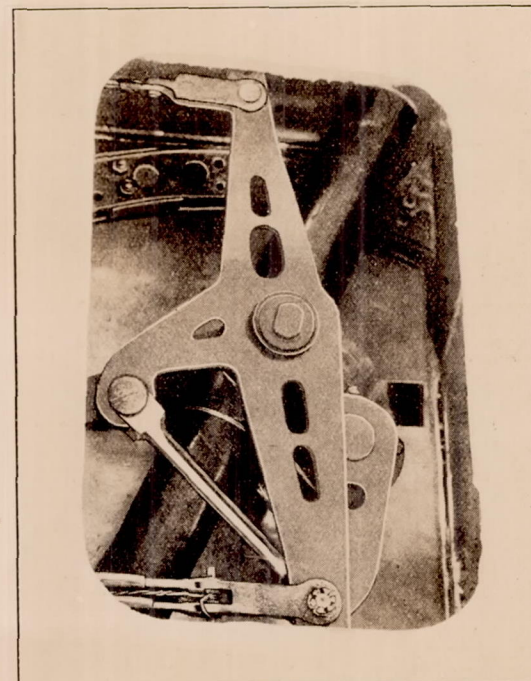


Fig. 12.  
Outer flap and aileron operating gear on D.H.54.